Lecture 04 – 05

Single-Stage Amplifiers

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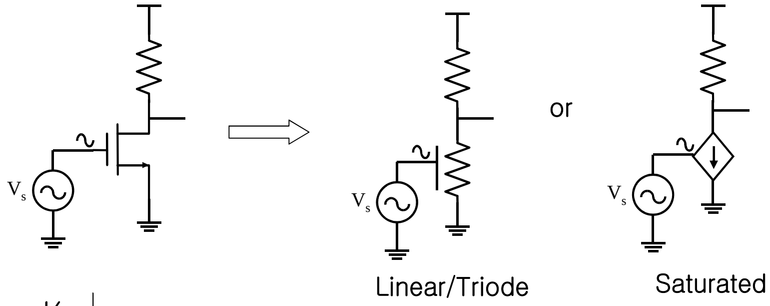
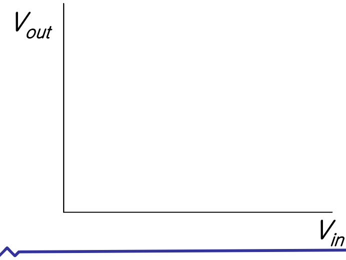
Introduction & Outline

- Why do we need an amplifier? Linear amplifier?
- Analyzing gain of amplifiers
- Common source amplifier
- Resistance of MOS
- Common gate amplifier
- Source Follower
- Cascode
- Current Mirrors

Single Stage Amplifier

- Intuitive large signal analysis

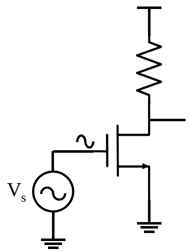


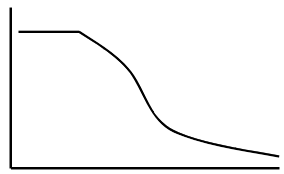


(1) $V_{in} < V_t$
(2) $V_{in} > V_t$, linear
(3) $V_{in} > V_t$, saturated

Common Source Amplifier

- Quantitative large signal analysis





*For linear amplification, input must be "small" and must have appropriate DC voltage (i.e. the transistor must be biased at a certain point) → Must be operated in the **saturated region**!*

$$V_o = V_{DD} - R_D I_D$$

(1) $V_{in} < V_t : I_D = 0$
(2) $V_{in} > V_t, V_o > V_{in} - V_t: I_D =$
(3) $V_{in} > V_t, V_o < V_{in} - V_t : I_D =$

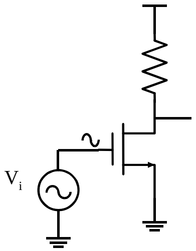
Obtaining A_v for *small enough* inputs

1. $V_o = V_{DD} - I_D(V_i)R_D$ → Obtain $v_o = f(v_i)$

2. $V_o = V_{DD} - I_D(V_i)R_D$ → Solve for dv_o/dv_i

3. Use Small Signal Model

1. Obtaining $v_o = f(v_i)$



$$
\begin{aligned}
\mathrm{V_o} &= V_{DD} - I_D R_D \\
&= V_{DD} - R_D \cdot k(V_i - V_{TH})^2 \\
&= V_{DD} - R_D \cdot k(V_{iDC} + v_i - V_{TH})^2
\end{aligned}
$$

2. Av = dv_o/dv_i

$$\mathrm{V_o} = V_{DD} - I_D R_D$$

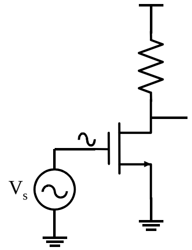
$$
\begin{aligned}
\frac{dV_o}{dV_i} &= -R_D \frac{dI_D}{dV_i} \\
&= -R_D g_m
\end{aligned}
$$

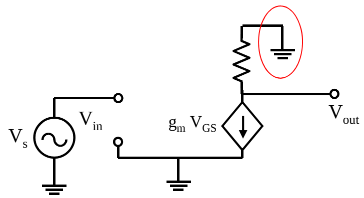
g_m = ?

- Linearized analysis!
  → Only works for “small” input signals under appropriate conditions

3. Small Signal Model

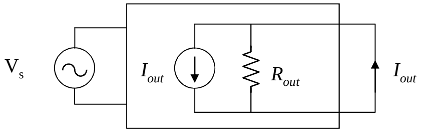
Note: how about current source?





$G_m R_{out}$

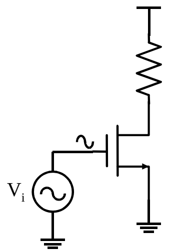
- In a linear circuit, the voltage gain is equal to $-G_m R_{out}$ where G_m is the transconductance of the circuit when the output is shorted to ground and R_{out} is the output resistance of the circuit when the input voltage is zero.

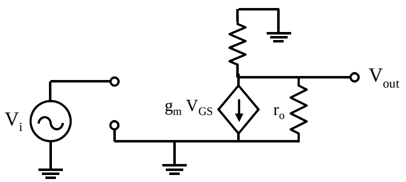


*Note $A_v = \dfrac{\sum \text{Output Resistance}}{\sum \text{Source Resistance}}$ → First Order Approximation. Good for first glance analysis only. (Needs accuracy improvement.)

Non-Ideality : g_{ds}

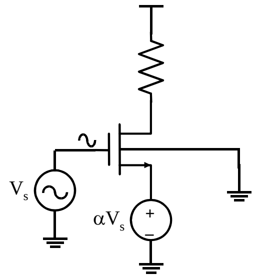
- Channel length modulation

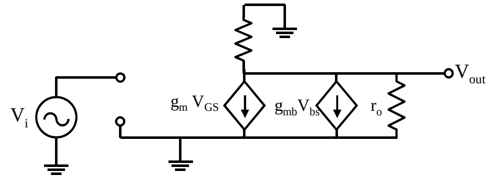




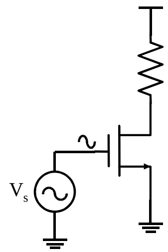
Non-Ideality : g_{mb}

- Body-effect : threshold voltage variation





Summary



- Transistor is a voltage-controlled current source
- For small enough signals at appropriate DC levels, transistor can be linearized.
- Non-idealities from channel length modulation and body-effect can decrease the gain

Biasing (Section 4.5 of Sedra/Smith)

1. Biasing with fixed V_{GS}

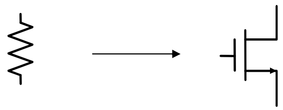
2. AC coupling capacitors with resistors

3. Current Sources

Note: Fig 4.33(a) of Sedra/Smith

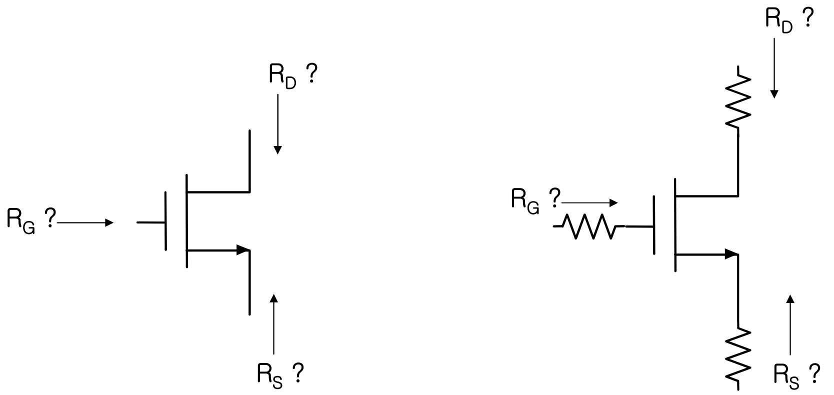
How to replace the "Resistor"

- Why replace resistor?
  - Resistor is expensive and very inaccurate in CMOS process
  - Achieve higher gain (small signal)
- Replace with what?
  - Transistors are FREE!
  - Not a linear resistor

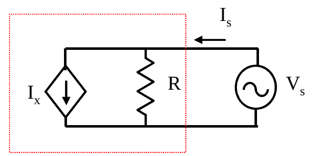


Which resistor (transconductance) do I use?

Small Signal Equivalent R in MOS



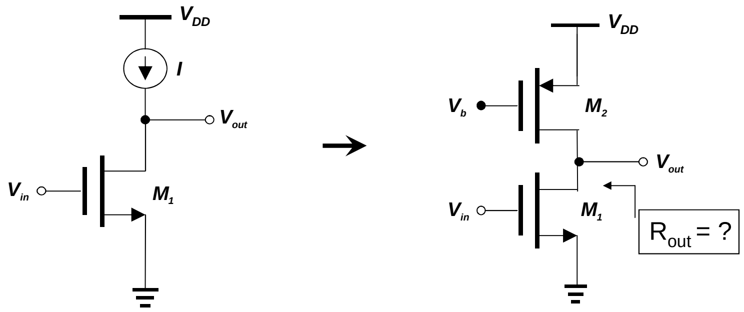
Resistance Multiplication



$$R_{\text{eff}} = R\left(1 - \frac{dI_x}{dI_s}\right)$$

e.g.) R = 1
Vs = 1V → 1.1V
Ix = 1A → 0.91A

Active Load

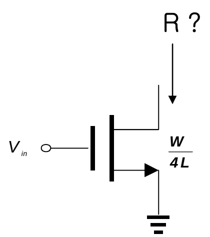


CS stage with Active (current source) load

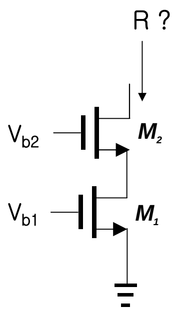
Av = ?

Increasing the output resistance

- Can we increase the resistance even higher?

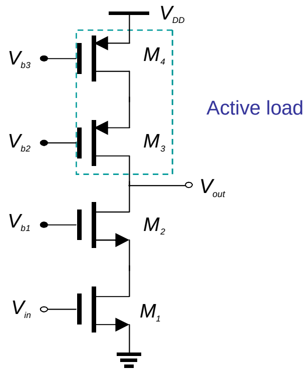


Increasing the channel length

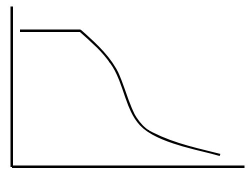


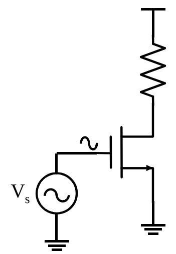
Cascode Stage

The MOS Cascode Amplifier



Problem of Common-Source Amp

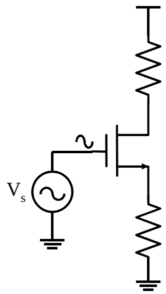




- Problem
  - limited linear range
  - input dependant gain
- Solution
  - reduce g_m
  - reduce sensitivity

Intuition: Vs rise → ID rise → Vs rise → Vgs fall → Id fall

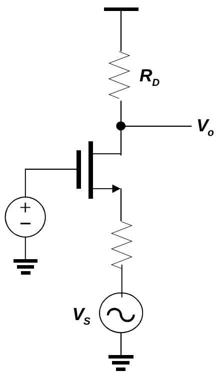
Solution: Degenerate Resistor



A_v =

R_{out} =

Common Gate Amplifier



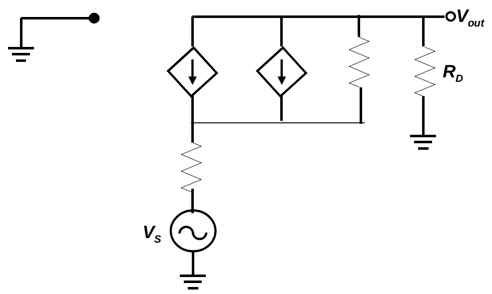
A_V = ?

R_{out} = ?

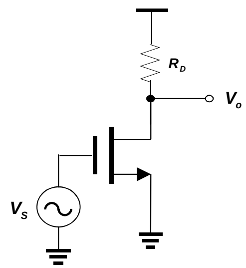
R_{in} = ?

Common Gate Amplifier

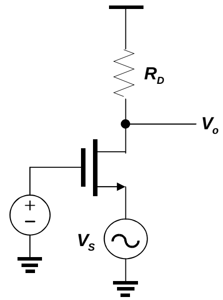
- small-signal model



CS Amplifier vs CG Amplifier



Common-Source Stage

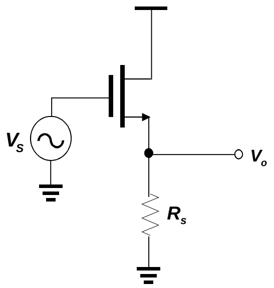


Common-Gate Stage

- High input resistance
- Large gain

- Current buffering property
- Superior high frequency response

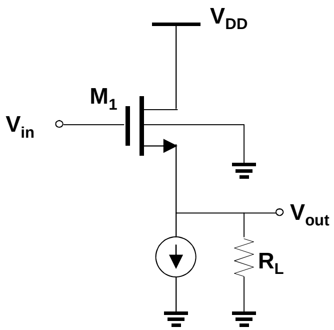
Source Follower



- Input resistance
- Output resistance
- Voltage gain

Problem! : I_D's depandancy on Vs !!

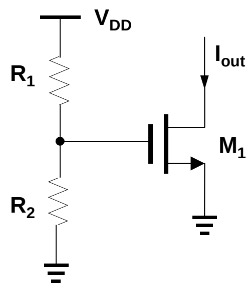
Source Follower with Current Source



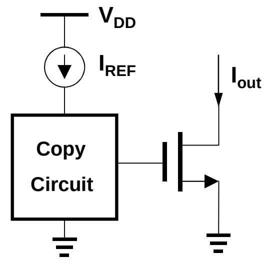
- Input resistance
- Output resistance
- Voltage gain

Note: Why can't this be used in common source amplifiers?

How can we provide accurate current?



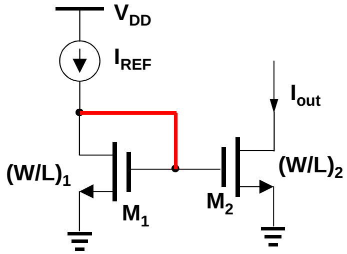
Definition of current by resistive divider



Conceptual means of copying currents

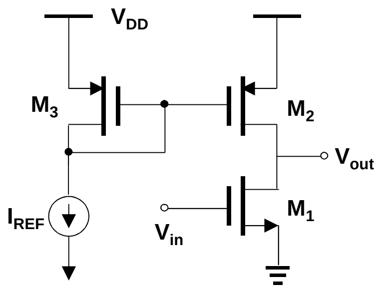
Could you set I_{out} stably?

Basic Concept of Current Mirror

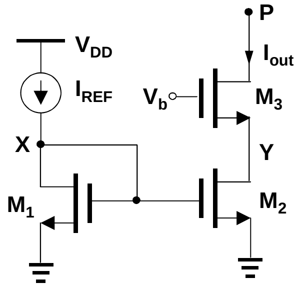


Basic current mirror

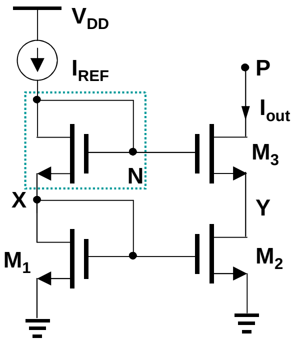
CS Amplifier with Active Load



Cascode Current Mirror

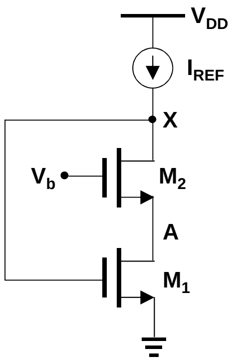


How can you set V_b ?



Cascode current mirror

*Cascode Mirror for Low-Voltage Operation



Summary

	Input resistance	Output resistance	Voltage gain
CS	∞		
CS with R_s	∞		
CG			
Source follower	∞		